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Gas-Insulated Substations

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A gas-insulated substation (GIS) uses a superior dielectric gas, SF₆, at moderate pressure for phase-to-phase and phase-to-ground insulation. The high voltage conductors, circuit breaker interrupters, switches, current transformers, and voltage transformers are in SF₆ gas inside grounded metal enclosures. The atmospheric air insulation used in a conventional, air-insulated substation (AIS) requires meters of air insulation to do what SF₆ can do in centimeters. GIS can therefore be smaller than AIS by up to a factor of 10. A GIS is mostly used where space is expensive or not available. In a GIS the active parts are protected from the deterioration from exposure to atmospheric air, moisture, contamination, etc. As a result, GIS is more reliable and requires less maintenance than AIS.

GIS was first developed in various countries between 1968 and 1972. After about 5 years of experience, the use rate increased to about 20% of new substations in countries where space is limited. In other countries with space easily available, the higher cost of GIS relative to AIS has limited use to special cases. For example, in the U.S., only about 2% of new substations are GIS. International experience with GIS is described in a series of CIGRE papers (CIGRE, 1992; 1994; 1982). The IEEE (IEEE Std. C37. 122-1993; IEEE Std C37. 122.1-1993) and the IEC (IEC, 1990) have standards covering all aspects of the design, testing, and use of GIS. For the new user, there is a CIGRE application guide (Katchinski et al., 1998). IEEE has a guide for specifications for GIS (IEEE Std. C37.123-1996).

2.1 SF₆

Sulfur hexafluoride is an inert, nontoxic, colorless, odorless, tasteless, and nonflammable gas consisting of a sulfur atom surrounded by and tightly bonded to six fluorine atoms. It is about five times as dense as air. SF₆ is used in GIS at pressures from 400 to 600 kPa absolute. The pressure is chosen so that the SF₆ will not condense into a liquid at the lowest temperatures the equipment experiences. SF₆ has two to three times the insulating ability of air at the same pressure. SF₆ is about 100 times better than air for

interrupting arcs. It is the universally used interrupting medium for high voltage circuit breakers, replacing the older mediums of oil and air. SF_6 decomposes in the high temperature of an electric arc, but the decomposed gas recombines back into SF_6 so well that it is not necessary to replenish the SF_6 in GIS. There are some reactive decomposition byproducts formed because of the trace presence of moisture, air, and other contaminants. The quantities formed are very small. Molecular sieve absorbants inside the GIS enclosure eliminate these reactive byproducts. SF_6 is supplied in 50-kg gas cylinders in a liquid state at a pressure of about 6000 kPa for convenient storage and transport. Gas handling systems with filters, compressors, and vacuum pumps are commercially available. Best practices and the personnel safety aspects of SF_6 gas handling are covered in international standards (IEC, 1995).

The SF_6 in the equipment must be dry enough to avoid condensation of moisture as a liquid on the surfaces of the solid epoxy support insulators because liquid water on the surface can cause a dielectric breakdown. However, if the moisture condenses as ice, the breakdown voltage is not affected. So dew points in the gas in the equipment need to be below about -10°C . For additional margin, levels of less than 1000 ppmv of moisture are usually specified and easy to obtain with careful gas handling. Absorbants inside the GIS enclosure help keep the moisture level in the gas low, even though over time, moisture will evolve from the internal surfaces and out of the solid dielectric materials (IEEE Std. 1125-1993).

Small conducting particles of mm size significantly reduce the dielectric strength of SF_6 gas. This effect becomes greater as the pressure is raised past about 600 kPa absolute (Cookson and Farish, 1973). The particles are moved by the electric field, possibly to the higher field regions inside the equipment or deposited along the surface of the solid epoxy support insulators, leading to dielectric breakdown at operating voltage levels. Cleanliness in assembly is therefore very important for GIS. Fortunately, during the factory and field power frequency high voltage tests, contaminating particles can be detected as they move and cause small electric discharges (partial discharge) and acoustic signals, so they can be removed by opening the equipment. Some GIS equipment is provided with internal “particle traps” that capture the particles before they move to a location where they might cause breakdown. Most GIS assemblies are of a shape that provides some “natural” low electric field regions where particles can rest without causing problems.

SF_6 is a strong greenhouse gas that could contribute to global warming. At an international treaty conference in Kyoto in 1997, SF_6 was listed as one of the six greenhouse gases whose emissions should be reduced. SF_6 is a very minor contributor to the total amount of greenhouse gases due to human activity, but it has a very long life in the atmosphere (half-life is estimated at 3200 years), so the effect of SF_6 released to the atmosphere is effectively cumulative and permanent. The major use of SF_6 is in electrical power equipment. Fortunately, in GIS the SF_6 is contained and can be recycled. By following the present international guidelines for use of SF_6 in electrical equipment (Mauthe et al., 1997), the contribution of SF_6 to global warming can be kept to less than 0.1% over a 100-year horizon. The emission rate from use in electrical equipment has been reduced over the last three years. Most of this effect has been due to simply adopting better handling and recycling practices. Standards now require GIS to leak less than 1% per year. The leakage rate is normally much lower. Field checks of GIS in service for many years indicate that the leak rate objective can be as low as 0.1% per year when GIS standards are revised.

2.2 Construction and Service Life

GIS is assembled of standard equipment modules (circuit breaker, current transformers, voltage transformers, disconnect and ground switches, interconnecting bus, surge arresters, and connections to the rest of the electric power system) to match the electrical one-line diagram of the substation. A cross-section view of a 242-kV GIS shows the construction and typical dimensions (Figure 2.1). The modules are joined using bolted flanges with an “O” ring seal system for the enclosure and a sliding plug-in contact for the conductor. Internal parts of the GIS are supported by cast epoxy insulators. These support insulators provide a gas barrier between parts of the GIS, or are cast with holes in the epoxy to allow gas to pass from one side to the other.

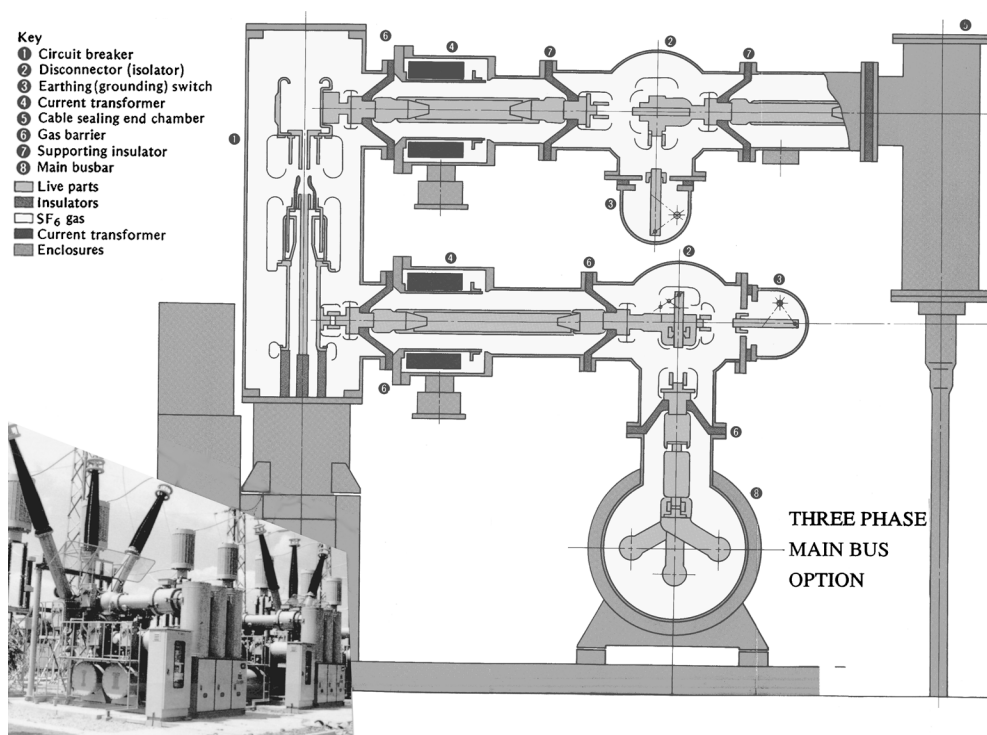


FIGURE 2.1 Single-phase enclosure GIS.

Up to about 170 kV system voltage, all three phases are often in one enclosure (Figure 2.2). Above 170 kV, the size of the enclosure for “three-phase enclosure,” GIS becomes too large to be practical. So a “single-phase enclosure” design (Figure 2.1) is used. There are no established performance differences between three-phase enclosure and single-phase enclosure GIS. Some manufacturers use the single-phase enclosure type for all voltage levels.

Enclosures today are mostly cast or welded aluminum, but steel is also used. Steel enclosures are painted inside and outside to prevent rusting. Aluminum enclosures do not need to be painted, but may be painted for ease of cleaning and a better appearance. The pressure vessel requirements for GIS enclosures are set by GIS standards (IEEE Std. C37.122-1993; IEC, 1990), with the actual design, manufacture, and test following an established pressure vessel standard of the country of manufacture. Because of the moderate pressures involved, and the classification of GIS as electrical equipment, third-party inspection and code stamping of the GIS enclosures are not required.

Conductors today are mostly aluminum. Copper is sometimes used. It is usual to silver plate surfaces that transfer current. Bolted joints and sliding electrical contacts are used to join conductor sections. There are many designs for the sliding contact element. In general, sliding contacts have many individually sprung copper contact fingers working in parallel. Usually the contact fingers are silver plated. A contact lubricant is used to ensure that the sliding contact surfaces do not generate particles or wear out over time. The sliding conductor contacts make assembly of the modules easy and also allow for conductor movement to accommodate the differential thermal expansion of the conductor relative to the enclosure. Sliding contact assemblies are also used in circuit breakers and switches to transfer current from the moving contact to the stationary contacts.

Support insulators are made of a highly filled epoxy resin cast very carefully to prevent formation of voids and/or cracks during curing. Each GIS manufacturer’s material formulation and insulator shape has been developed to optimize the support insulator in terms of electric field distribution, mechanical strength, resistance to surface electric discharges, and convenience of manufacture and assembly. Post,

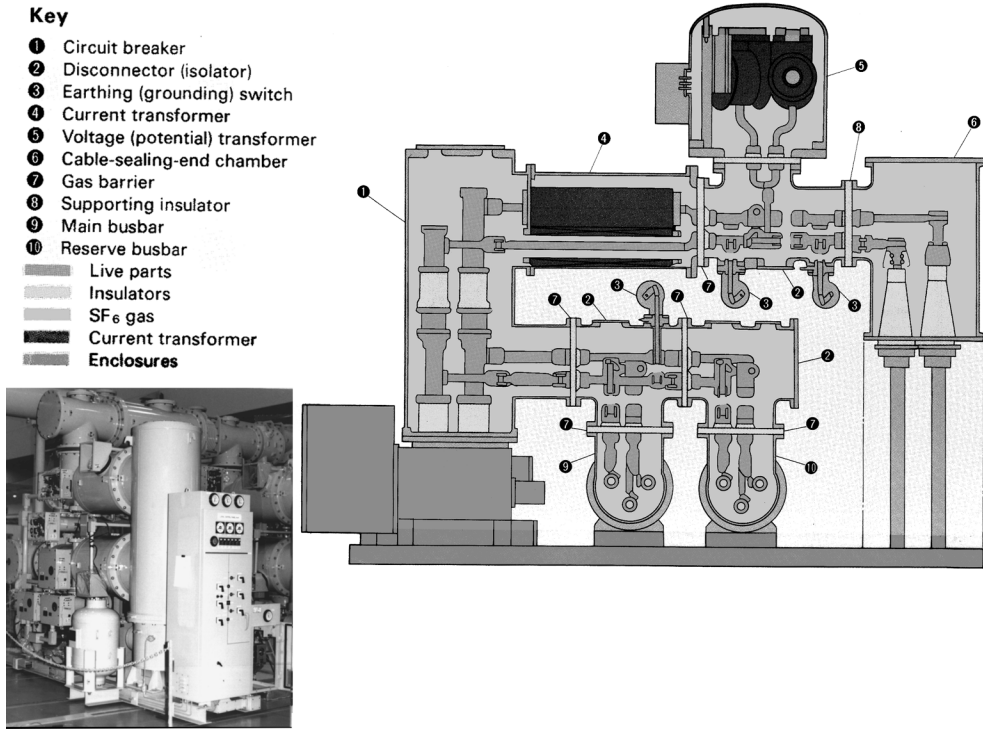


FIGURE 2.2 Three-phase enclosure GIS.

disc, and cone type support insulators are used. Quality assurance programs for support insulators include a high voltage power frequency withstand test with sensitive partial discharge monitoring. Experience has shown that the electric field stress inside the cast epoxy insulator should be below a certain level to avoid aging of the solid dielectric material. The electrical stress limit for the cast epoxy support insulator is not a severe design constraint because the dimensions of the GIS are mainly set by the lightning impulse withstand level and the need for the conductor to have a fairly large diameter to carry to load current of several thousand amperes. The result is space between the conductor and enclosure for support insulators having low electrical stress.

Service life of GIS using the construction described above has been shown by experience to be more than 30 years. The condition of GIS examined after many years in service does not indicate any approaching limit in service life. Experience also shows no need for periodic internal inspection or maintenance. Inside the enclosure is a dry, inert gas that is itself not subject to aging. There is no exposure of any of the internal materials to sunlight. Even the “O” ring seals are found to be in excellent condition because there is almost always a “double seal” system — Figure 2.3 shows one approach. The lack of aging has been found for GIS, whether installed indoors or outdoors.

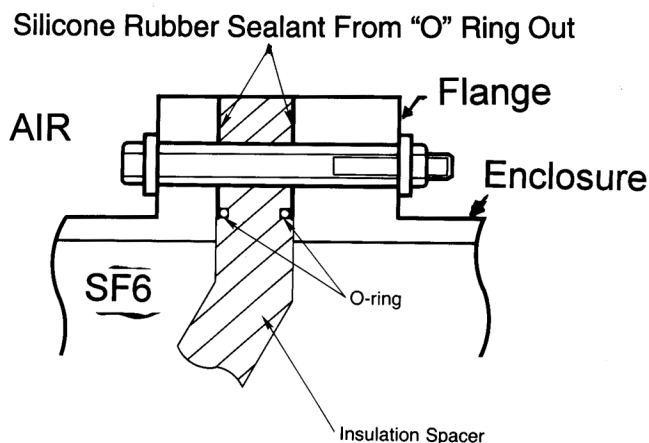
2.2.1 Circuit Breaker

GIS uses essentially the same dead tank SF₆ puffer circuit breakers used in AIS. Instead of SF₆-to-air as connections into the substation as a whole, the nozzles on the circuit breaker enclosure are directly connected to the adjacent GIS module.

2.2.2 Current Transformers

CTs are inductive ring types installed either inside the GIS enclosure or outside the GIS enclosure (Figure 2.4). The GIS conductor is the single turn primary for the CT. CTs inside the enclosure must be

GAS SEAL FOR GIS ENCLOSURE



"O"-ring is primary seal

Silicone rubber sealant is backup seal and protects "O"-ring and flange surfaces

FIGURE 2.3 Gas seal for GIS enclosure.

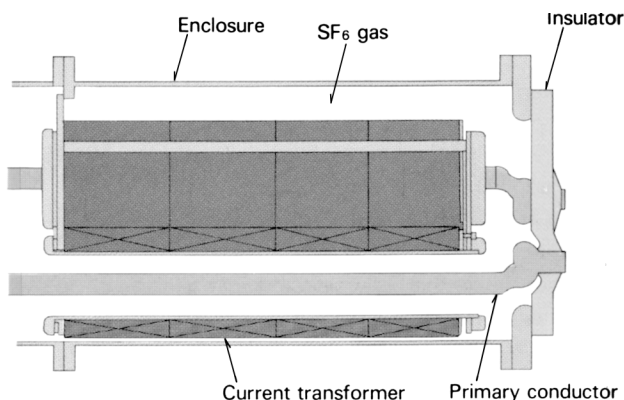


FIGURE 2.4 Current transformers for GIS.

shielded from the electric field produced by the high voltage conductor or high transient voltages can appear on the secondary through capacitive coupling. For CTs outside the enclosure, the enclosure itself must be provided with an insulating joint, and enclosure currents shunted around the CT. Both types of construction are in wide use.

2.2.3 Voltage Transformers

VTs are inductive types with an iron core. The primary winding is supported on an insulating plastic film immersed in SF₆. The VT should have an electric field shield between the primary and secondary windings to prevent capacitive coupling of transient voltages. The VT is usually a sealed unit with a gas barrier insulator. The VT is either easily removable so the GIS can be high voltage tested without damaging the VT, or the VT is provided with a disconnect switch or removable link ([Figure 2.5](#)).

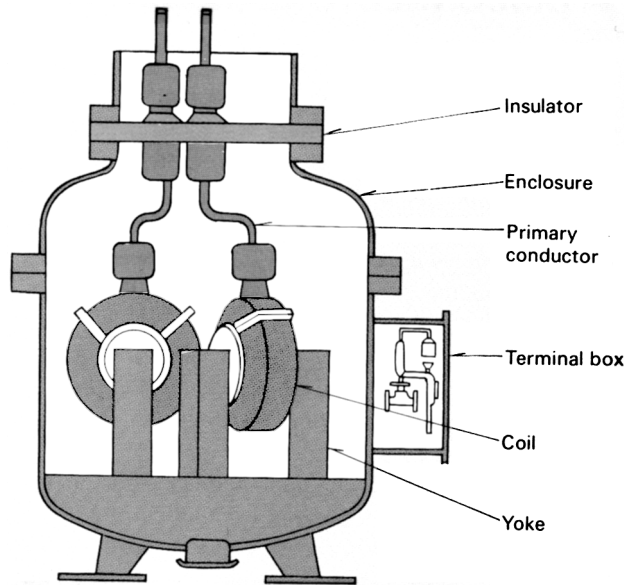


FIGURE 2.5 Voltage transformers for GIS.

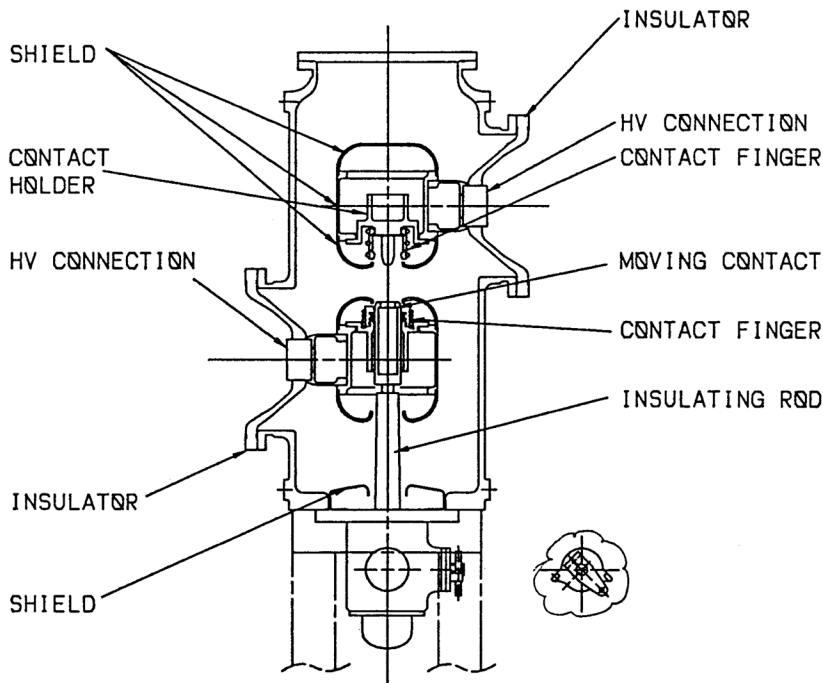


FIGURE 2.6 Disconnect switches for GIS.

2.2.4 Disconnect Switches

Disconnect switches (Figure 2.6) have a moving contact that opens or closes a gap between stationary contacts when activated by an insulating operating rod that is itself moved by a sealed shaft coming through the enclosure wall. The stationary contacts have shields that provide the appropriate electric field distribution

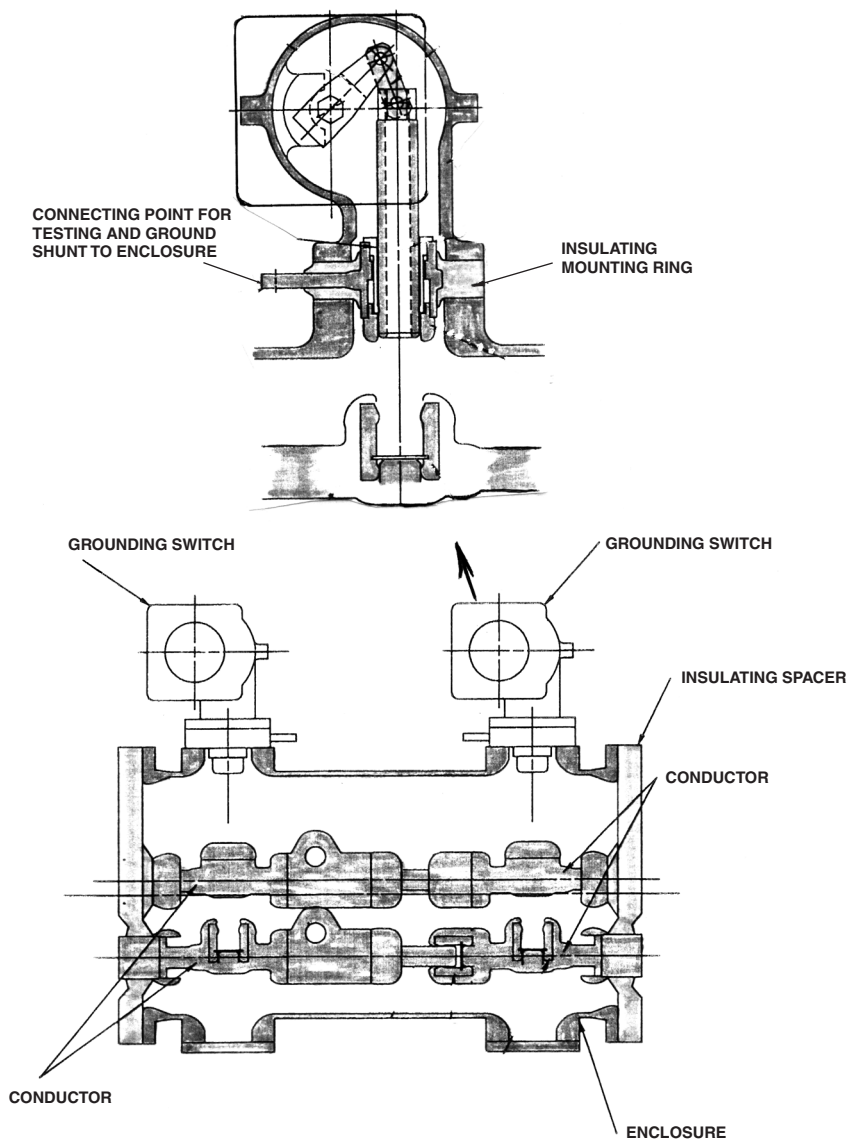


FIGURE 2.7 Ground switches for GIS.

to avoid too high a surface stress. The moving contact velocity is relatively low (compared to a circuit breaker moving contact) and the disconnect switch can interrupt only low levels of capacitive current (for example, disconnecting a section of GIS bus) or small inductive currents (for example, transformer magnetizing current). Load break disconnect switches have been furnished in the past, but with improvements and cost reductions of circuit breakers, it is not practical to continue to furnish load break disconnect switches, and a circuit breaker should be used instead.

2.2.5 Ground Switches

Ground switches (Figure 2.7) have a moving contact that opens or closes a gap between the high voltage conductor and the enclosure. Sliding contacts with appropriate electric field shields are provided at the enclosure and the conductor. A “maintenance” ground switch is operated either manually or by motor

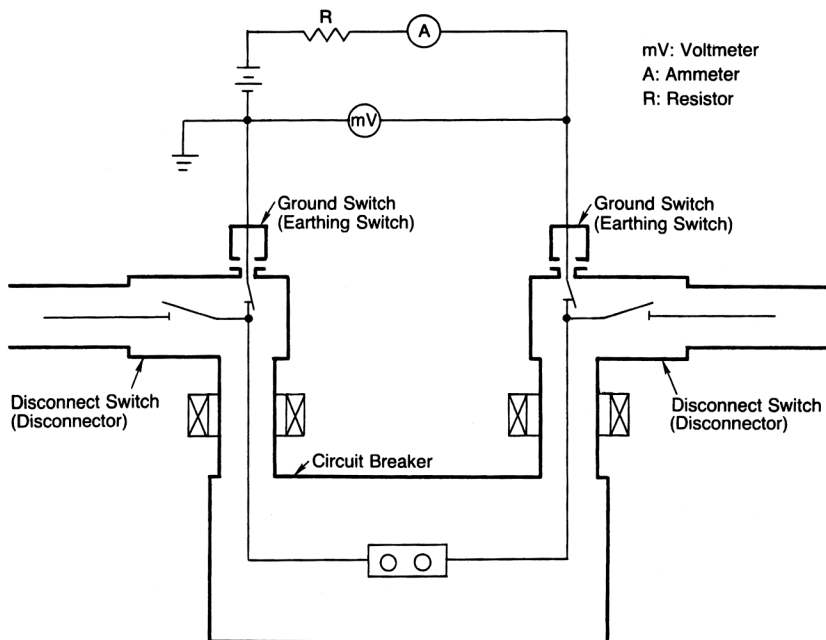


FIGURE 2.8 Contact resistance measured using ground switch.

drive to close or open in several seconds and when fully closed to carry the rated short-circuit current for the specified time period (1 or 3 sec) without damage. A “fast-acting” ground switch has a high speed drive, usually a spring, and contact materials that withstand arcing so it can be closed twice onto an energized conductor without significant damage to itself or adjacent parts. Fast-acting ground switches are frequently used at the connection point of the GIS to the rest of the electric power network, not only in case the connected line is energized, but also because the fast-acting ground switch is better able to handle discharge of trapped charge and breaking of capacitive or inductive coupled currents on the connected line.

Ground switches are almost always provided with an insulating mount or an insulating bushing for the ground connection. In normal operation the insulating element is bypassed with a bolted shunt to the GIS enclosure. During installation or maintenance, with the ground switch closed, the shunt can be removed and the ground switch used as a connection from test equipment to the GIS conductor. Voltage and current testing of the internal parts of the GIS can then be done without removing SF_6 gas or opening the enclosure. A typical test is measurement of contact resistance using two ground switches (Figure 2.8).

2.2.6 Bus

To connect GIS modules that are not directly connected to each other, an SF_6 bus consisting of an inner conductor and outer enclosure is used. Support insulators, sliding electrical contacts, and flanged enclosure joints are usually the same as for the GIS modules.

2.2.7 Air Connection

SF_6 -to-air bushings (Figure 2.9) are made by attaching a hollow insulating cylinder to a flange on the end of a GIS enclosure. The insulating cylinder contains pressurized SF_6 on the inside and is suitable for exposure to atmospheric air on the outside. The conductor continues up through the center of the insulating cylinder to a metal end plate. The outside of the end plate has provisions for bolting to an air insulated conductor. The insulating cylinder has a smooth interior. Sheds on the outside improve the

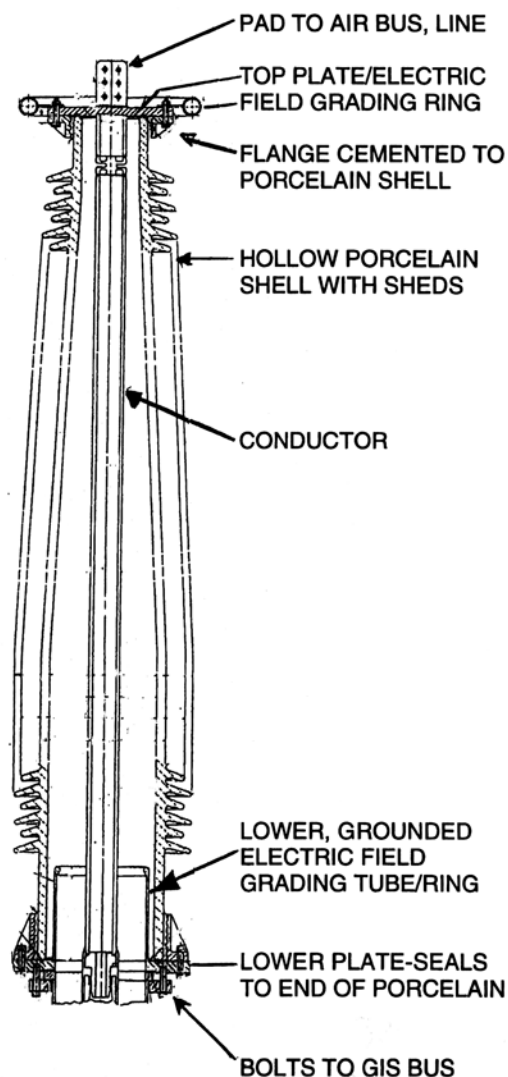


FIGURE 2.9 SF₆-to-air bushing.

performance in air under wet and/or contaminated conditions. Electric field distribution is controlled by internal metal shields. Higher voltage SF₆-to-air bushings also use external shields. The SF₆ gas inside the bushing is usually the same pressure as the rest of the GIS. The insulating cylinder has most often been porcelain in the past, but today many are a composite consisting of a fiberglass epoxy inner cylinder with an external weather shed of silicone rubber. The composite bushing has better contamination resistance and is inherently safer because it will not fracture as will porcelain.

2.2.8 Cable Connections

A cable connecting to a GIS is provided with a cable termination kit that is installed on the cable to provide a physical barrier between the cable dielectric and the SF₆ gas in the GIS (Figure 2.10). The cable termination kit also provides a suitable electric field distribution at the end of the cable. Because the cable termination will be in SF₆ gas, the length is short and sheds are not needed. The cable conductor is connected with bolted or compression connectors to the end plate or cylinder of the cable termination

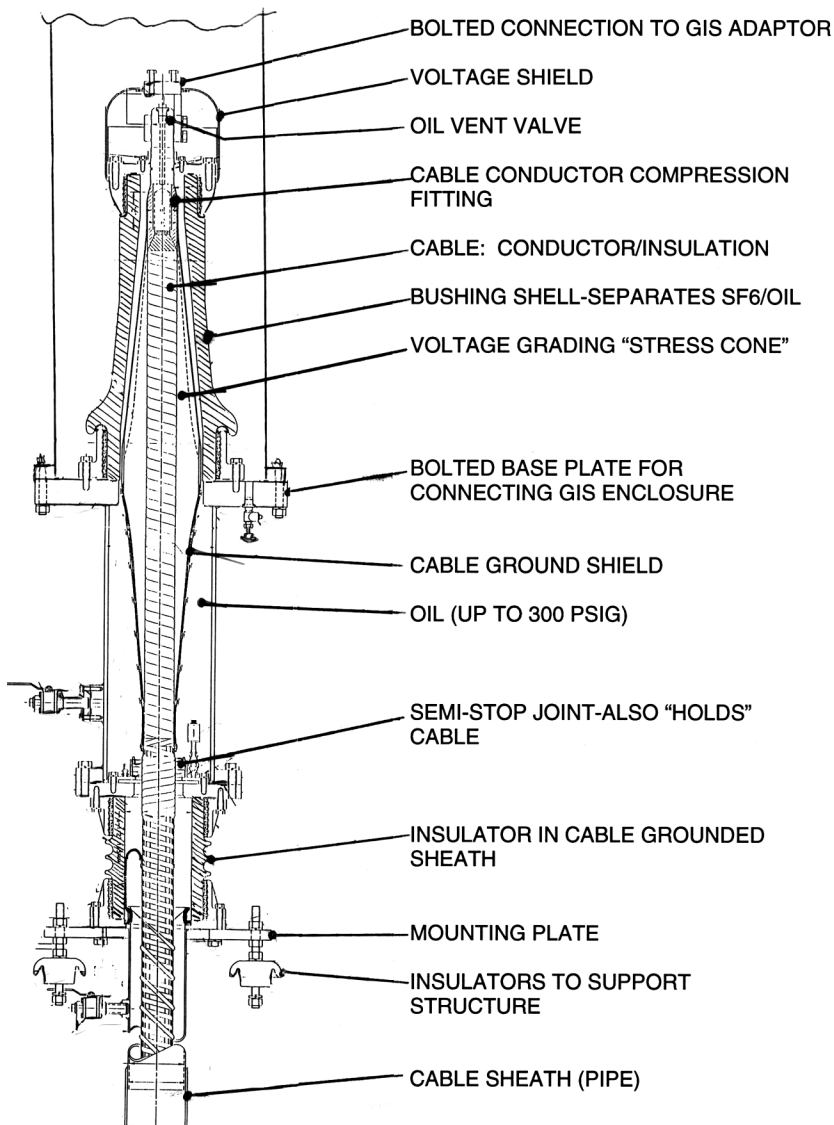


FIGURE 2.10 Power cable connection.

kit. On the GIS side, a removable link or plug in contact transfers current from the cable to the GIS conductor. For high voltage testing of the GIS or the cable, the cable is disconnected from the GIS by removing the conductor link or plug-in contact. The GIS enclosure around the cable termination usually has an access port. This port can also be used for attaching a test bushing.

2.2.9 Direct Transformer Connections

To connect a GIS directly to a transformer, a special SF_6 -to-oil bushing that mounts on the transformer is used (Figure 2.11). The bushing is connected under oil on one end to the transformer's high voltage leads. The other end is SF_6 and has a removable link or sliding contact for connection to the GIS conductor. The bushing may be an oil-paper condenser type or more commonly today, a solid insulation type. Because leakage of SF_6 into the transformer oil must be prevented, most SF_6 -to-oil bushings have a center

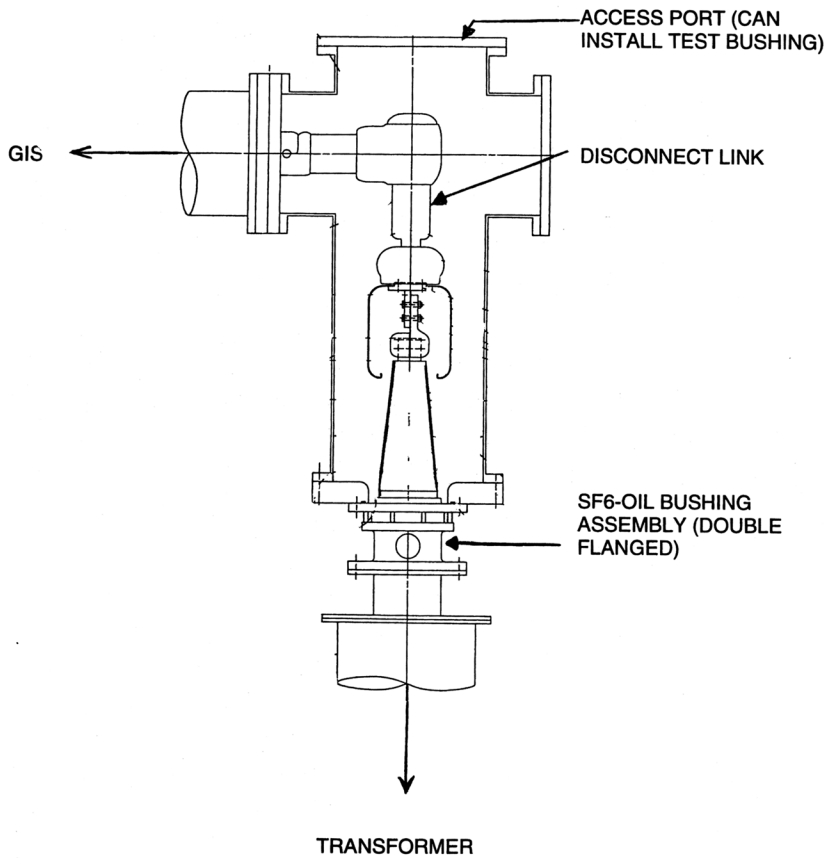


FIGURE 2.11 Direct SF₆ bus connection to transformer.

section that allows any SF₆ leakage to go to the atmosphere rather than into the transformer. For testing, the SF₆ end of the bushing is disconnected from the GIS conductor after gaining access through an opening in the GIS enclosure. The GIS enclosure of the transformer can also be used for attaching a test bushing.

2.2.10 Surge Arrester

Zinc oxide surge arrester elements suitable for immersion in SF₆ are supported by an insulating cylinder inside a GIS enclosure section to make a surge arrester for overvoltage control ([Figure 2.12](#)). Because the GIS conductors are inside a grounded metal enclosure, the only way for lightning impulse voltages to enter is through the connections of the GIS to the rest of the electrical system. Cable and direct transformer connections are not subject to lightning strikes, so only at SF₆-to-air bushing connections is lightning a concern. Air-insulated surge arresters in parallel with the SF₆-to-air bushings usually provide adequate protection of the GIS from lightning impulse voltages at a much lower cost than SF₆ insulated arresters. Switching surges are seldom a concern in GIS because with SF₆ insulation the withstand voltages for switching surges are not much less than the lightning impulse voltage withstand. In AIS there is a significant decrease in withstand voltage for switching surges than for lightning impulse because the longer time span of the switching surge allows time for the discharge to completely bridge the long insulation distances in air. In the GIS, the short insulation distances can be bridged in the short time span of a lightning impulse so the longer time span of a switching surge does not significantly decrease the breakdown voltage. Insulation coordination studies usually show there is no need for surge arresters

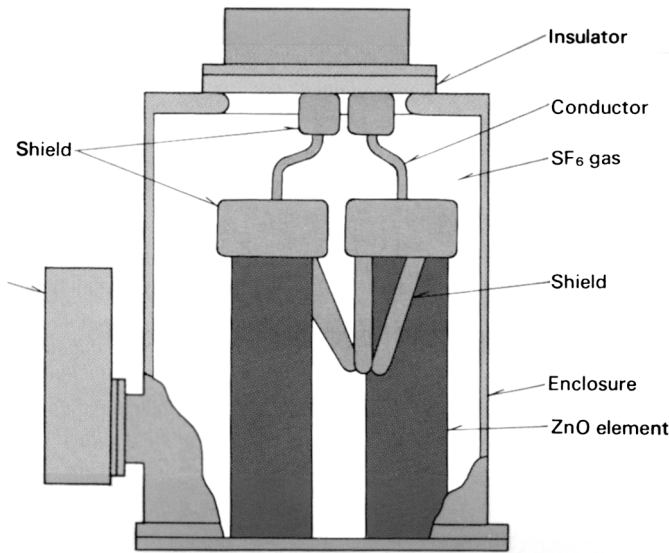


FIGURE 2.12 Surge arrester for GIS.

in a GIS; however, many users specify surge arresters at transformers and cable connections as the most conservative approach.

2.2.11 Control System

For ease of operation and convenience in wiring the GIS back to the substation control room, a local control cabinet (LCC) is provided for each circuit breaker position ([Figure 2.13](#)). The control and power wires for all the operating mechanisms, auxiliary switches, alarms, heaters, CTs, and VTs are brought from the GIS equipment modules to the LCC using shielded multiconductor control cables. In addition to providing terminals for all the GIS wiring, the LCC has a mimic diagram of the part of the GIS being controlled. Associated with the mimic diagram are control switches and position indicators for the circuit breaker and switches. Annunciation of alarms is also usually provided in the LCC. Electrical interlocking and some other control functions can be conveniently implemented in the LCC. Although the LCC is an extra expense, with no equivalent in the typical AIS, it is so well established and popular that attempts to eliminate it to reduce cost have not succeeded. The LCC does have the advantage of providing a very clear division of responsibility between the GIS manufacturer and user in terms of scope of equipment supply.

Switching and circuit breaker operation in a GIS produces internal surge voltages with a very fast rise time on the order of nanoseconds and a peak voltage level of about 2 per unit. These “very fast transient overvoltages” are not a problem inside the GIS because the duration of this type of surge voltage is very short — much shorter than the lightning impulse voltage. However, a portion of the VFTO will emerge from the inside of the GIS at any place where there is a discontinuity of the metal enclosure — for example, at insulating enclosure joints for external CTs or at the SF₆-to-air bushings. The resulting “transient ground rise voltage” on the outside of the enclosure may cause some small sparks across the insulating enclosure joint or to adjacent grounded parts. These may alarm nearby personnel but are not harmful to a person because the energy content is very low. However, if these VFT voltages enter the control wires, they could cause faulty operation of control devices. Solid-state controls can be particularly affected. The solution is thorough shielding and grounding of the control wires. For this reason, in a GIS, the control cable shield should be grounded at both the equipment and the LCC ends using either coaxial ground bushings or short connections to the cabinet walls at the location where the control cable first enters the cabinet.

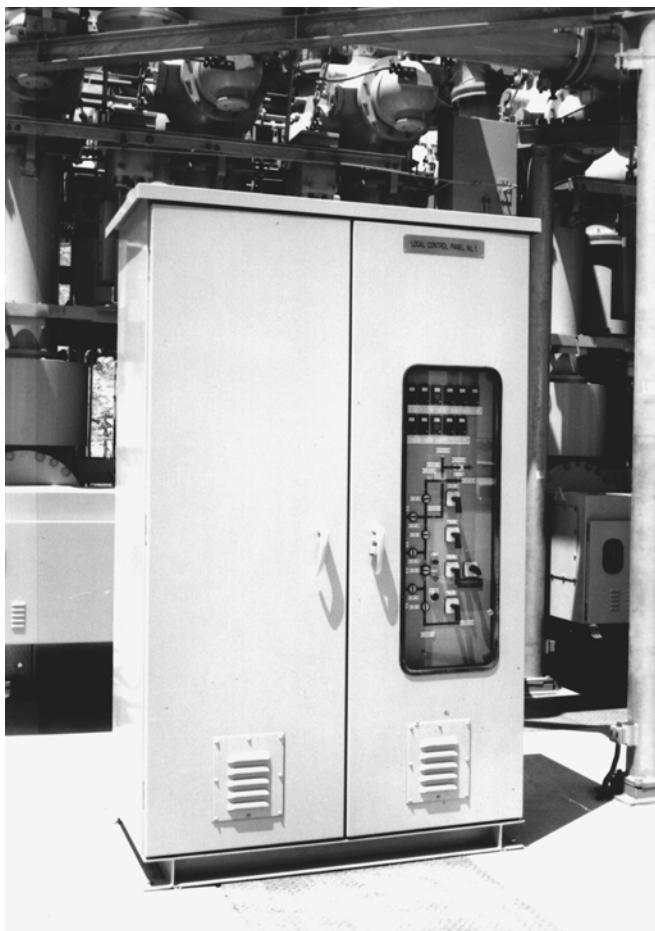


FIGURE 2.13 Local control cabinet for GIS.

2.2.12 Gas Monitor System

The insulating and interrupting capability of the SF_6 gas depends on the density of the SF_6 gas being at a minimum level established by design tests. The pressure of the SF_6 gas varies with temperature, so a mechanical temperature-compensated pressure switch is used to monitor the equivalent of gas density (Figure 2.14). GIS is filled with SF_6 to a density far enough above the minimum density for full dielectric and interrupting capability so that from 10 to 20% of the SF_6 gas can be lost before the performance of the GIS deteriorates. The density alarms provide a warning of gas being lost, and can be used to operate the circuit breakers and switches to put a GIS that is losing gas into a condition selected by the user. Because it is much easier to measure pressure than density, the gas monitor system usually has a pressure gage. A chart is provided to convert pressure and temperature measurements into density. Microprocessor-based measurement systems are available that provide pressure, temperature, density, and even percentage of proper SF_6 content. These can also calculate the rate at which SF_6 is being lost. However, they are significantly more expensive than the mechanical temperature-compensated pressure switches, so they are supplied only when requested by the user.

2.2.13 Gas Compartments and Zones

A GIS is divided by gas barrier insulators into gas compartments for gas handling purposes. In some cases, the use of a higher gas pressure in the circuit breaker than is needed for the other devices, requires

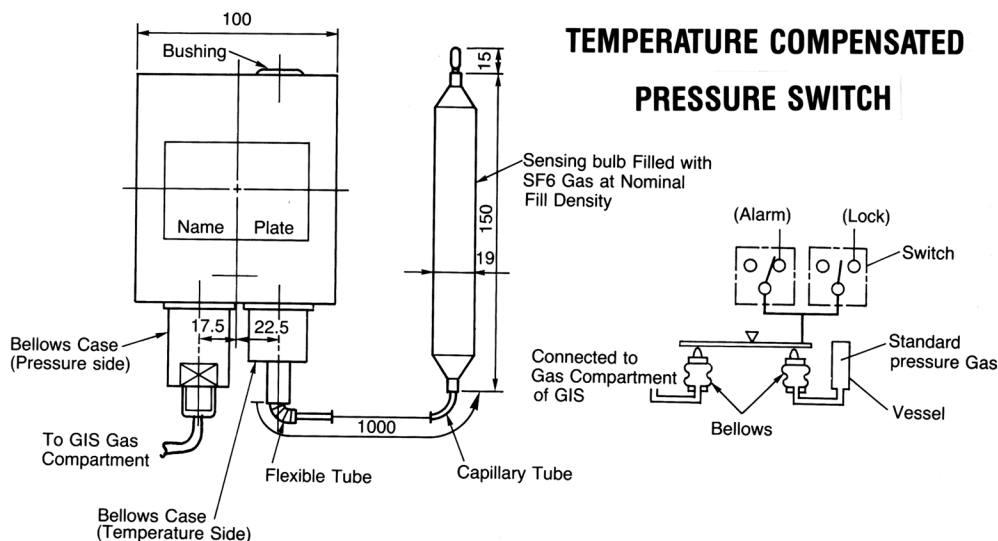


FIGURE 2.14 SF₆ density monitor for GIS.

that the circuit breaker be a separate gas compartment. Gas handling systems are available to easily process and store about 1000 kg of SF₆ at one time, but the length of time needed to do this is longer than most GIS users will accept. GIS is therefore divided into relatively small gas compartments of less than several hundred kg. These small compartments may be connected with external bypass piping to create a larger gas zone for density monitoring. The electrical functions of the GIS are all on a three-phase basis, so there is no electrical reason not to connect the parallel phases of a single-phase enclosure type of GIS into one gas zone for monitoring. Reasons for not connecting together many gas compartments into large gas zones include a concern with a fault in one gas compartment causing contamination in adjacent compartments and the greater amount of SF₆ lost before a gas loss alarm. It is also easier to locate a leak if the alarms correspond to small gas zones, but a larger gas zone will, for the same size leak, give more time to add SF₆ between the first alarm and second alarm. Each GIS manufacturer has a standard approach to gas compartments and gas zones, but will, of course, modify the approach to satisfy the concerns of individual GIS users.

2.2.14 Electrical and Physical Arrangement

For any electrical one-line diagram there are usually several possible physical arrangements. The shape of the site for the GIS and the nature of connecting lines and/or cables should be considered. Figure 2.15 compares a “natural” physical arrangement for a breaker and a half GIS with a “linear” arrangement.

Most GIS designs were developed initially for a double bus, single breaker arrangement (Figure 2.2). This widely used approach provides good reliability, simple operation, easy protective relaying, excellent economy, and a small footprint. By integrating several functions into each GIS module, the cost of the double bus, single breaker arrangement can be significantly reduced. An example is shown in Figure 2.16. Disconnect and ground switches are combined into a “three-position switch” and made a part of each bus module connecting adjacent circuit breaker positions. The cable connection module includes the cable termination, disconnect switches, ground switches, a VT, and surge arresters.

2.2.15 Grounding

The individual metal enclosure sections of the GIS modules are made electrically continuous either by the flanged enclosure joint being a good electrical contact in itself or with external shunts bolted to the flanges or to grounding pads on the enclosure. While some early single-phase enclosure GIS were “single

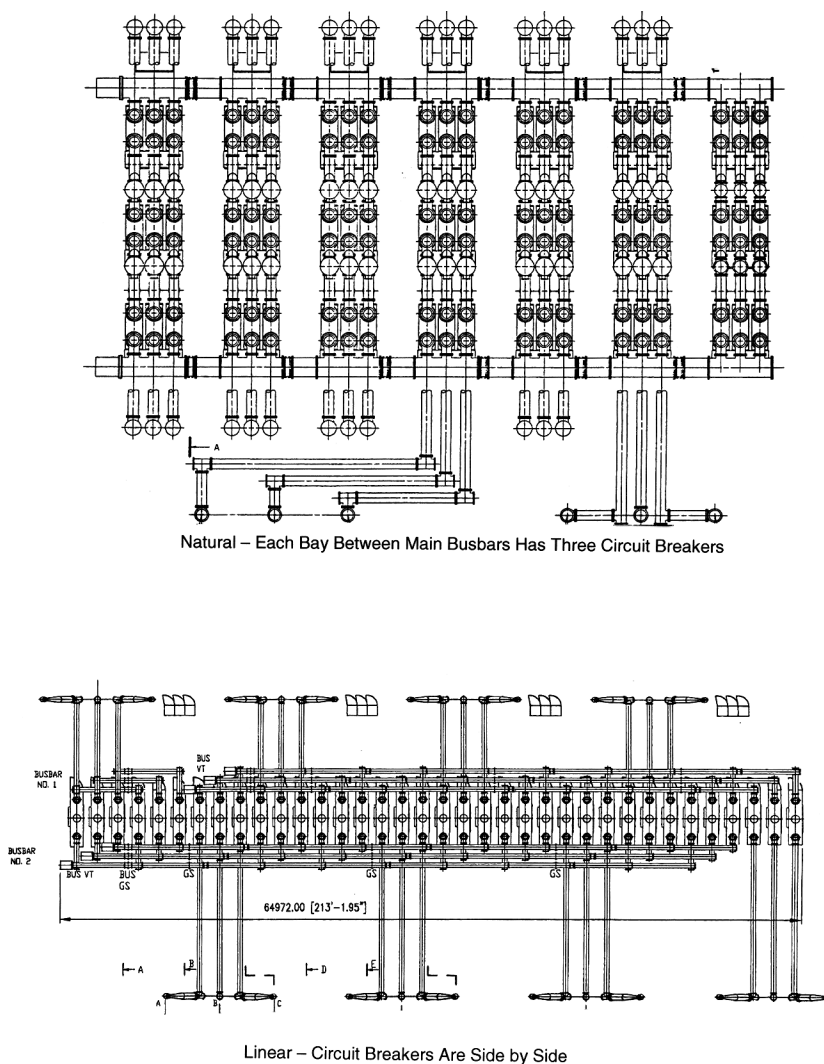


FIGURE 2.15 One-and-one-half circuit breaker layouts.

point grounded” to prevent circulating currents from flowing in the enclosures, today the universal practice is to use “multipoint grounding” even though this leads to some electrical losses in the enclosures due to circulating currents. The three enclosures of a single-phase GIS should be bonded to each other at the ends of the GIS to encourage circulating currents to flow. These circulating enclosure currents act to cancel the magnetic field that would otherwise exist outside the enclosure due to the conductor current. Three-phase enclosure GIS does not have circulating currents, but does have eddy currents in the enclosure, and should also be multipoint grounded. With multipoint grounding and the resulting many parallel paths for the current from an internal fault to flow to the substation ground grid, it is easy to keep the touch and step voltages for a GIS to the safe levels prescribed in IEEE 80.

2.2.16 Testing

Test requirements for circuit breakers, CTs, VTs, and surge arresters are not specific for GIS and will not be covered in detail here. Representative GIS assemblies having all of the parts of the GIS except for the circuit breaker are design tested to show that the GIS can withstand the rated lightning impulse voltage,

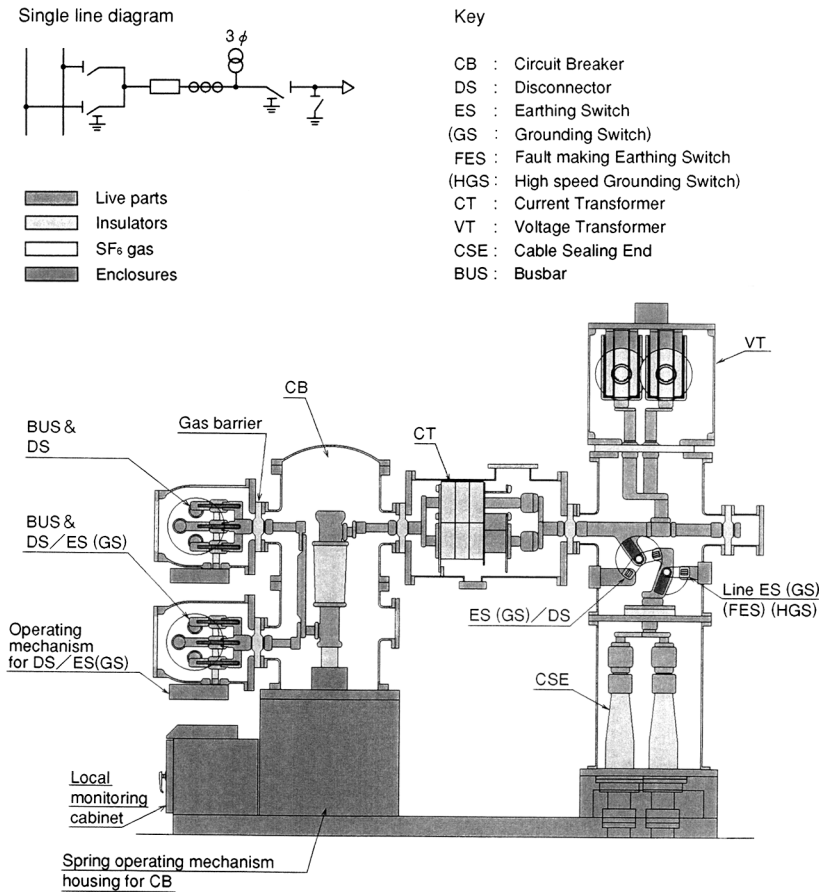


FIGURE 2.16 Integrated (combined function) GIS.

switching impulse voltage, power frequency overvoltage, continuous current, and short-circuit current. Standards specify the test levels and how the tests must be done. Production tests of the factory-assembled GIS (including the circuit breaker) cover power frequency withstand voltage, conductor circuit resistance, leak checks, operational checks, and CT polarity checks. Components such as support insulators, VTs, and CTs are tested in accordance with the specific requirements for these items before assembly into the GIS. Field tests repeat the factory tests. The power frequency withstand voltage test is most important as a check of the cleanliness of the inside of the GIS in regard to contaminating conducting particles, as explained in the SF₆ section above. Checking of interlocks is also very important. Other field tests may be done if the GIS is a very critical part of the electric power system, when, for example, a surge voltage test may be requested.

2.2.17 Installation

The GIS is usually installed on a monolithic concrete pad or the floor of a building. It is most often rigidly attached by bolting and/or welding the GIS support frames to embedded steel plates or beams. Chemical drill anchors can also be used. Expansion drill anchors are not recommended because dynamic loads may loosen expansion anchors when the circuit breaker operates. Large GIS installations may need bus expansion joints between various sections of the GIS to adjust to the fit-up in the field and, in some cases, provide for thermal expansion of the GIS. The GIS modules are shipped in the largest practical assemblies. At the lower voltage level, two or more circuit breaker positions can be delivered fully

assembled. The physical assembly of the GIS modules to each other using the bolted flanged enclosure joints and sliding conductor contacts goes very quickly. More time is used for evacuation of air from gas compartments that have been opened, filling with SF₆ gas, and control system wiring. The field tests are then done. For a high voltage GIS shipped as many separate modules, installation and testing takes about two weeks per circuit breaker position. Lower voltage systems shipped as complete bays, and mostly factory-wired, can be installed more quickly.

2.2.18 Operation and Interlocks

Operation of a GIS in terms of providing monitoring, control, and protection of the power system as a whole is the same as for an AIS except that internal faults are not self-clearing so reclosing should not be used for faults internal to the GIS. Special care should be taken for disconnect and ground switch operation because if these are opened with load current flowing, or closed into load or fault current, the arcing between the switch moving and stationary contacts will usually cause a phase-to-phase fault in three-phase enclosure GIS or to a phase-to-ground fault in single-phase enclosure GIS. The internal fault will cause severe damage inside the GIS. A GIS switch cannot be as easily or quickly replaced as an AIS switch. There will also be a pressure rise in the GIS gas compartment as the arc heats the gas. In extreme cases, the internal arc will cause a rupture disk to operate or may even cause a burn-through of the enclosure. The resulting release of hot, decomposed SF₆ gas may cause serious injury to nearby personnel. For both the sake of the GIS and the safety of personnel, secure interlocks are provided so that the circuit breaker must be open before an associated disconnect switch can be opened or closed, and the disconnect switch must be open before the associated ground switch can be closed or opened.

2.2.19 Maintenance

Experience has shown that the internal parts of GIS are so well protected inside the metal enclosure that they do not age and as a result of proper material selection and lubricants, there is negligible wear of the switch contacts. Only the circuit breaker arcing contacts and the teflon nozzle of the interrupter experience wear proportional to the number of operations and the level of the load or fault currents being interrupted. Good contact and nozzle materials combined with the short interrupting time of modern circuit breakers provide, typically, for thousands of load current interruption operations and tens of full-rated fault current interruptions before there is any need for inspection or replacement. Except for circuit breakers in special use such as at a pumped storage plant, most circuit breakers will not be operated enough to ever require internal inspection. So most GIS will not need to be opened for maintenance. The external operating mechanisms and gas monitor systems should be visually inspected, with the frequency of inspection determined by experience.

2.3 Economics of GIS

The equipment cost of GIS is naturally higher than that of AIS due to the grounded metal enclosure, the provision of an LCC, and the high degree of factory assembly. A GIS is less expensive to install than an AIS. The site development costs for a GIS will be much lower than for an AIS because of the much smaller area required for the GIS. The site development advantage of GIS increases as the system voltage increases because high voltage AIS take very large areas because of the long insulating distances in atmospheric air. Cost comparisons in the early days of GIS projected that, on a total installed cost basis, GIS costs would equal AIS costs at 345 kV. For higher voltages, GIS was expected to cost less than AIS. However, the cost of AIS has been reduced significantly by technical and manufacturing advances (especially for circuit breakers) over the last 30 years, but GIS equipment has not shown any cost reduction until very recently. Therefore, although GIS has been a well-established technology for a long time, with a proven high reliability and almost no need for maintenance, it is presently perceived as costing too much and is only applicable in special cases where space is the most important factor.

Currently, GIS costs are being reduced by integrating functions as described in the arrangement section above. As digital control systems become common in substations, the costly electromagnetic CTs and VTs of a GIS will be replaced by less-expensive sensors such as optical VTs and Rogowski coil CTs. These less-expensive sensors are also much smaller, reducing the size of the GIS and allowing more bays of GIS to be shipped fully assembled. Installation and site development costs are correspondingly lower. The GIS space advantage over AIS increases. GIS can now be considered for any new substation or the expansion of an existing substation without enlarging the area for the substation.

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